CHAPTER 6: FLUID INCLUSION STUDIES

6.1 INTRODUCTION ...

This chapter presents the results of a detailed fluid inclusion study of the paragenetic stages within the Federal-Bassett Fault at Renison. Numerous investigations of fluid inclusions associated with mineralisation in the Renison Tin Mine have been undertaken by previous researchers. Collins (1972) undertook the first microthermometric measurements on three fluorite specimens to establish a temperature for stratabound mineralisation. Patterson (1979) supplemented these temperature estimates with a study of four quartz and two fluorite samples from vein mineralisation in the Federal-Bassett Fault. In addition to heating stage experiments, Patterson (1979) also analysed the composition of fourteen samples using bulk extraction techniques. Davies (1985) performed the first freezing point depression measurements in an extensive investigation of stratabound mineralisation. Holyland (1987) used fluid inclusion data from a number of paragenetic stages to constrain parameters used to model fluid flow, deformation, and mass and heat transfer at Renison.

The aim of this investigation is to describe fluid inclusions associated with the vein paragenesis and related deformation events recognised in the Federal-Bassett Fault (Chapter 5). This data will be used to evaluate the spatial and temporal evolution of hydrothermal fluids responsible for cassiterite deposition within the Federal-Bassett Fault. Temporal evolution of the mineralising fluids at Renison is considered by comparing data from each paragenetic stage in the Federal-Bassett Fault. Spatial physicochemical variations for the Federal-Bassett Fault are discussed by comparing fluid inclusions within each paragenetic stage from the fault over its maximum vertical extent (1200 m), beginning at the contact with the underlying Pine Hill Granite, for a total strike length of two kilometres.

6.2 METHOD OF STUDY ...

Primary fluid inclusions are visible in zoned cassiterite, quartz, fluorite (rarely) and calcite associated with Federal-Bassett Fault mineralisation. The majority of fluid inclusions at Renison are small, typically less than 5 μm in diameter (Collins, 1972; Patterson, 1979; Davies, 1985; Holyland, 1987). The size of fluid inclusions necessitated a total of 253 polished thin sections and 192 doubly polished sections to be prepared for qualitative and descriptive investigation during this study. From these, 66 doubly polished thin sections

were selected for heating and freezing experiments on a total of 75 wafers. Fluid inclusions were examined from every stage of the vein paragenesis, with the exception of the supergene stage which contained no workable material. A total of 629 fluid inclusions have been analysed. Fluid inclusions were classified in a temporal sense as primary, pseudo-secondary and secondary (Appendix VI) relative to their host mineral and time of trapping. Of those studied, 186 are considered to be primary and the remaining 443 are classified as pseudo-secondary or secondary. Minerals hosting fluid inclusions at Renison frequently show growth zoned patterns (quartz, cassiterite and rarely fluorite and calcite) which are typically recognised by colour variations or alignments of occluded solid phases. Only fluid inclusions formed during this primary growth phase have been classified as primary (e.g., Shepherd *et al.*, 1985; Reynolds, 1990). Alternative criteria defined by Roedder (1984) for a primary origin such as isolated, solitary fluid inclusions or those exhibiting negative crystal shapes have not been applied in this study; and all such fluid inclusions are classified as secondary. Pseudo-secondary fluid inclusions typically have homogenisation temperatures identical to or slightly lower than corresponding primary fluid inclusions from the same sample. They have been grouped together with secondary fluid inclusions for all statistical considerations due to ambiguities concerning their accurate classification (e.g., problems with grain boundary trails). All fluid inclusion data collected during this study are tabulated in Appendix VI.

Microthermometry was performed at the University of Tasmania on a modified USGS gas-flow heating/freezing stage supplied by Fluid Inc (Sterner & Bodnar, 1984; Bodnar & Sterner, 1985). Calibration of the stage was performed using synthetic fluid inclusions manufactured by Syn Flinc, and the precision of measured temperatures are ± 1.0°C for heating and ± 0.3°C for freezing. The accuracy of the Trendicator thermocouple measurements were calibrated against the triple point of CO_2 (-56.6°C), the freezing point of water (0.0°C), and the critical point of water (374.1°C) in synthetic fluid inclusions.

Homogenisation temperatures, which represent minimum trapping temperatures, have not been corrected for pressure because critical homogenisation behaviour and palaeosurface estimates indicate hydrostatic conditions (Section 6.6.4), requiring a maximum pressure correction of ~15°C for a 10 wt. % NaCl solution (Potter *et al.*, 1977). Such values are considered within the range of experimental error. Salinities for halite-saturated and halite-undersaturated fluid inclusions were determined using the algorithm of Bodnar *et al.* (1989) and expressed as equivalent NaCl weight percent (eq. wt. % NaCl). The input data required for these calculations consisted of measured freezing point depressions for undersaturated fluid inclusions and halite dissolution temperatures for hypersaline fluid inclusions. In multi-phase fluid inclusions, this method only provides a rough estimate of the true salinity, because contributions to the total salinity by salts other than NaCl and KCl are not considered.

A small proportion (<1%) of the fluid inclusions examined contained visible CO_2. In CO_2-bearing fluid inclusions, CO_2 hydrates form on cooling and cause CO_2 and H_2O to be extracted from the solution which results in an apparent increase in the salinity (Collins, 1979). Therefore, in two-phase liquid and vapour fluid inclusions which showed CO_2 clathration (formation of CO_2 hydrates), the decomposition temperature of the hydrates were determined and the salinity estimated using the equation of Bozzo *et al.* (1973).

6.3 Classification Of Fluid Inclusion Types ...

Seven distinct fluid inclusion types have been identified in the Federal-Bassett Fault mineralisation at Renison, based on phase relations observed at room temperature (Nash, 1976; Table 6.1). The fluid inclusion types are:

Type $\overline{1A}$: Two-phase liquid-rich fluid inclusions that homogenise by vapour bubble disappearance **(Plate 6.1A)**. Type 1A fluid inclusions are abundant in all stages of fault mineralisation.

Type 1B: Rare three-phase liquid-rich fluid inclusions that contain an opaque daughter mineral (possibly accidental solid inclusions of sulphides) and homogenise by vapour bubble disappearance. The daughter minerals do not dissolve **(Plate 6.1B)**. This fluid inclusion type only occurs in sulphide stage fluid inclusions.

Type 2: Rare two-phase vapour-rich fluid inclusions homogenise by vapour bubble expansion or exhibit critical homogenisation behaviour by fading of the meniscus without a change in the size of the vapour phase **(Plate 6.1C)**. This behaviour was only observed in a few isolated fluid inclusions from the oxide-silicate stage of mineralisation.

Type 3AD: Three-phase liquid-rich hypersaline fluid inclusions (liquid + vapour + halite) which homogenise by vapour bubble disappearance **(Plate 6.1D)**. This fluid inclusion type only occurs as secondary fluid inclusions in sulphide stage mineralisation.

Type 3BV: Three-phase liquid-rich fluid inclusions (liquid + vapour + carbonate daughter(s) ± unknowns daughters) that homogenise by vapour bubble disappearance. Type 3BV fluid inclusions occur in all vein stages, but are most abundant in the sulphide stage **(Plate 6.1E)**.

Type 4: Rare CO_2-rich fluid inclusions that contain CO_2 liquid and gas plus H_2O-liquid (± daughter minerals) are restricted to the sulphide stage of mineralisation **(Plate 6.1F)**.

Type 5: Rare secondary single-phase liquid fluid inclusions occur in both the sulphide and base metal stages of mineralisation**(Plate 6.1G)**.

The number of each type of fluid inclusion, analysed from each paragenetic stage is presented in Table 6.2. Each fluid inclusion type has been further divided into both primary and secondary fluid inclusions.

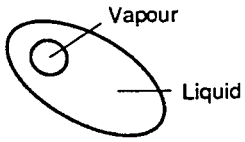
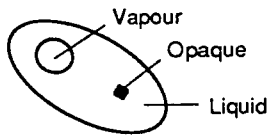
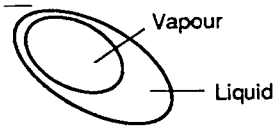
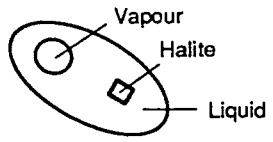
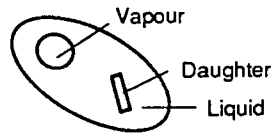
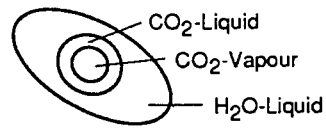
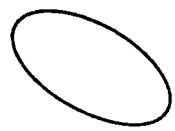
INCLUSION TYPE		PHASES AT 25°C	HOMOGENISATION BEHAVIOUR
Type 1A		Liquid + vapour	Vapour disappears
Type 1B		Liquid + vapour + opaque	Vapour disappears
Type 2		Vapour + liquid	Critical Behaviour
Type 3AD		Liquid + vapour + halite (± other daughters)	Vapour disappears
Type 3BV		Liquid + vapour + daughter(s) (1 - 5)	Vapour disappears
Type 4		CO_2-liquid + CO_2-vapour + H_2O-liquid	CO_2 disappears
Type 5		Single phase	N.A.

Table 6.1 Summary of fluid inclusion types, the phase(s) present at 25°C, and the high temperature homogenisation behaviour.

PLATE 6.1

A: Type 1A fluid inclusion. Zoned cassiterite with a solitary 30 μm fluid inclusion with liquid + vapour formed within a growth zone, but exhibiting possible necked characteristics. Sample No. 111125: DDH U0825 (v) 79.5 m. Abbreviations: Cass - cassiterite, Liq - liquid, Vap - vapour.

B: Type 1B fluid inclusion. Main sulphide stage fluorite containing solitary 15 μm fluid inclusions with liquid + vapour + opaque daughter + carbonate daughter minerals. The sulphide daughter mineral is pyrrhotite. Sample No. 111100: DDH U0777 (iii) 97.8 m. Abbreviations: Carb - carbonate, Flu - fluorite, Liq - liquid, Sulf - sulphide, Vap - vapour.

C: Type 2 fluid inclusion. Oxide-silicate stage quartz containing solitary 5 μm fluid inclusion with vapour + liquid. These inclusions exhibited critical homogenisation behaviour. Sample No. 111107: DDH U0797 (i) 114.2 m. Abbreviations: Liq - liquid, Qz - quartz, Vap - vapour.

D: Type 3AD fluid inclusion. Main sulphide stage fluorite containing solitary 7 μm fluid inclusion with liquid + vapour + halite daughter + carbonate daughter minerals. Sample No. 111088: DDH U0638 (vii) 97.9 m. Abbreviations: Carb - carbonate, Flu - fluorite, Hal - halite, Liq - liquid, Vap - vapour.

E: Type 3BV fluid inclusion. Main sulphide stage fluorite containing a secondary trail of 30 μm fluid inclusions with liquid + vapour + carbonate daughter + unknown daughter mineral. Sample No. 111088: DDH U0638 (vii) 97.9 m. Abbreviations: Carb - carbonate, Flu - fluorite, Liq - liquid, Vap - vapour.

F: Type 4 fluid inclusion. Main sulphide stage fluorite containing a secondary trail of 10 μm fluid inclusions with CO_2-liquid + CO_2-vapour + H_2O-liquid. Sample No. 111088: DDH U0638 (vii) 97.9 m. Abbreviations: CO_2-liq - CO_2 liquid, CO_2-vap - CO_2 vapour, Flu - fluorite, H_2O-liq - water.

G: Type 5 fluid inclusions. Vug-fill carbonate stage fluorite containing secondary trails of 5 μm fluid inclusions with liquid only or vapour only contents. These secondary trails of fluid inclusions are considered to be associated with boiling. Sample No. 111180: DDH U1036 (i) 29.5 m. Abbreviations: Flu - fluorite, Liq - liquid, Vap - vapour.

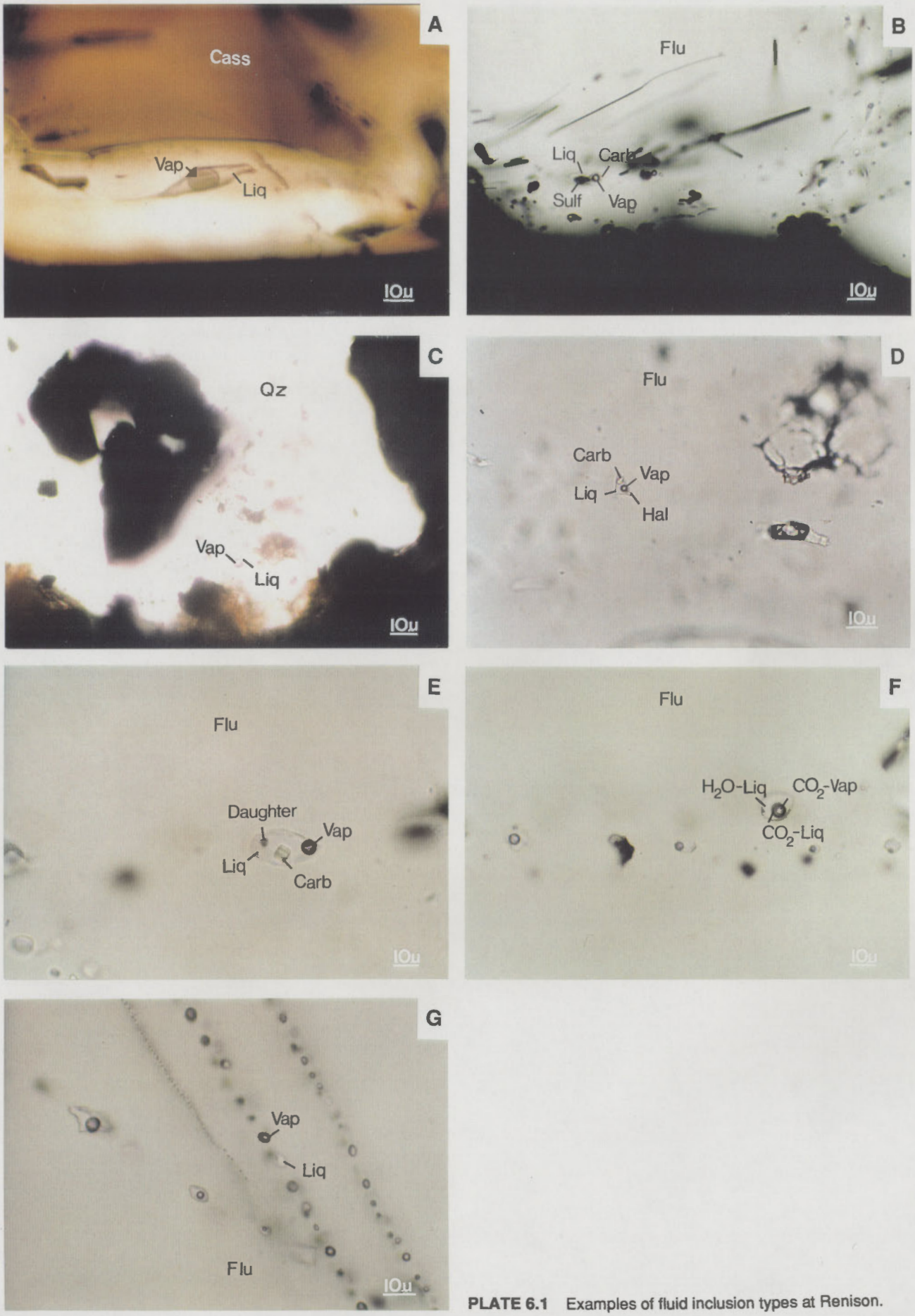


PLATE 6.1 Examples of fluid inclusion types at Renison.

Table 6.2: Summary of the fluid inclusion data collected from the Federal-Bassett Fault showing the fluid inclusion types together with their primary (P) or secondary (S) classification, the mineralogical stages, and the number of fluid inclusions where data was collected. Pseudosecondary fluid inclusions are grouped with the secondary inclusions.

STAGE	Type 1A		Type 1B		Type 2		Type 3AD		Type 3BV		Type 4		Type 5	
	P	S	P	S	P	S	P	S	P	S	P	S	P	S
Oxide-silicate	23	27	-	-	-	5	-	-	24	24	-	-	-	-
Sulphide	38	168	-	2	-	-	-	6	37	43	6	1	-	3
Base Metal	28	15	-	-	-	-	-	-	10	30	-	-	-	3
Carbonate	8	115	-	-	-	-	-	-	12	1	-	-	-	-

6.4 FLUID INCLUSION PETROGRAPHY ...

Textural relationships, distribution and characteristics of the various fluid inclusion types in each host mineral are described below.

6.4.1 Fluid Inclusions In Cassiterite ...

Cassiterite occurs as zoned euhedral to subhedral crystals with secular or normal twinning in the oxide-silicate and sulphide stages of vein mineralisation associated with the Federal-Bassett Fault. None of the previous fluid inclusion investigations at Renison successfully obtained data from cassiterite. As this study is primarily concerned with the physicochemical conditions associated with cassiterite deposition, considerable effort went into obtaining cassiterite with workable fluid inclusions. The dark-brown to honey coloured nature of Renison cassiterite results in poor optical clarity for fluid inclusion study, and while visibility is acceptable at room temperature, the cassiterite crystals typically become dark during freezing and heating runs, making collection of microthermometric data difficult.

Almost half of the fluid inclusion data for the oxide-silicate stage has been collected from zoned cassiterite. However, the poor optical clarity during freezing runs prevented estimates of the salinities in all but one quarter of the inclusions from which homogenisation temperatures were obtained. Fluid inclusion types 1A and 3BV are divided equally amongst the cassiterite hosted fluid inclusions in the oxide-silicate and sulphide stages of mineralisation. There are no apparent spatial controls on the distribution of these two fluid inclusion types along the Federal-Bassett Fault. Cassiterite in the sulphide stage of the vein

paragenesis is less amenable to fluid inclusion work, and accounts for less than 3 percent of the total amount of data collected for this paragenetic stage.

6.4.2 Fluid Inclusions In Quartz ...

Zoned quartz crystals host most of the workable fluid inclusions at Renison. Quartz occurs in all paragenetic stages associated with the Federal-Bassett Fault, and consequently provides the most complete record of fluid evolution with geologic time.

Fluid inclusion types 1A and 3BV predominantly occur in quartz from all paragenetic stages. The two inclusion types occur throughout the Federal-Bassett Fault with no obvious spatial controls on their distribution. Rare Type 2 (two-phase vapour-rich), Type 4 (CO_2-bearing) and Type 5 (single-phase) fluid inclusions are hosted by quartz crystals. Type 2 fluid inclusions occur in oxide-silicate stage mineralisation as 5 μm individual fluid inclusions in euhedral quartz intergrown with arsenopyrite, cassiterite and pyrrhotite. Type 4 fluid inclusions (average 5 μm diameter) are associated with the sulphide stage, occurring in euhedral quartz crystals that also contain cassiterite and minor pyrrhotite inclusions. The quartz crystals are intergrown with massive, strained and recrystallised pyrrhotite. Type 5 fluid inclusions are up to 25 μm in diameter and occur as isolated fluid inclusions in sulphide stage quartz intergrown with pyrrhotite and arsenopyrite.

6.4.3 Fluid Inclusions In Fluorite ...

Fluorite occurs as a minor accessory phase in all but the supergene stage of mineralisation associated with the Federal-Bassett Fault. Due to fluorite's perfect cleavage, multiple populations of secondary fluid inclusions have been trapped along healed fractures in this mineral. Fluorite, however, rarely exhibits growth zones and when present, comprise predominantly occluded solid phases.

Subhedral grains of fluorite associated with late oxide-silicate stage mineral assemblages in the lower fault area are overprinted and intergrown with chlorite and chalcopyrite. Isolated Type 1A fluid inclusions (average 10 μm diameter) are characteristic. Fluorite associated with the sulphide stage contains Type 1A and 3BV fluid inclusions interspersed throughout the Federal-Bassett Fault. Rare isolated Type 1B and Type 3AD fluid inclusions also occur in fluorite from the sulphide stage. The base metal and carbonate stage fluorites contain Type 3BV and Type 1A inclusions respectively, that range between 5 μm and 15 μm in diameter. Fluid inclusions in both paragenetic stages occur as isolated fluid inclusions or as secondary trails along healed fractures.

6.4.4 Fluid Inclusions In Carbonate ...

Recrystallised dolomite associated with the margin of a base metal vein (specimen 111142) contains the only known example of workable primary fluid inclusions in carbonate associated with the Federal-Bassett Fault. They occur as primary elongate 5 μm Type 1A fluid inclusions within growth zones of a single euhedral dolomite crystal.

6.5 FLUID INCLUSION MICROTHERMOMETRY ...

6.5.1 Oxide-Silicate Stage Fluid Inclusions ...

The oxide-silicate stage of mineralisation is dominated by Type 1A and Type 3BV fluid inclusions, with rare Type 3AD and Type 2 fluid inclusions (Fig. 6.1). Fluid inclusions range in size from less than 3 μm to 50 μm in diameter, but typically are ≤ 10 μm. Primary fluid inclusions associated with growth zones in host minerals are rare. Isolated fluid inclusions are far more common but have been classified, together with pseudo-secondary inclusions, as secondary in this study (Shepherd *et al.*, 1985; Reynolds, 1990).

Homogenisation temperatures for primary oxide-silicate stage fluid inclusions range from 270° to 420°C; most occur between 340° and 420°C (Fig. 6.1A). These temperatures are consistent with those reported for oxide-silicate stages of cassiterite mineralisation world-wide (Kelly & Turneaure, 1970; Taylor, 1979; Haapala & Kinnunen, 1982; Kwak, 1987; Heinrich, 1990; Solomon & Groves, 1994) but are significantly higher than the temperatures obtained from the earliest paragenetic stages by Collins (1972), Patterson (1979), Davies (1985) and Holyland (1987) for Renison. Primary Type 1A fluid inclusions mostly yield significantly higher homogenisation temperatures than Type 3BV fluid inclusions (Fig. 6.1A). Secondary fluid inclusions display a bimodal distribution; the high temperature fluid inclusions reach a maximum between 320° and 380°C, similar to the primary fluid inclusion population, and the low temperature fluid inclusions reach a maximum between 220° and 250°C (Fig. 6.1C). The low temperature homogenisation population in the secondary fluid inclusions may reflect an overprint of the next paragenetic stage (Section 6.5.2). Homogenisation temperature for Type 1A secondary fluid inclusions are consistently higher than secondary Type 3BV fluid inclusions. Type 3BV fluid inclusions associated with the oxide-silicate stage typically contain a birefringent daughter mineral. Homogenisation by the vapour bubble to the liquid phase occurs before final dissolution of the daughter mineral. Continued heating results in decrepitation of Type 3BV fluid inclusions prior to daughter mineral dissolution, although evidence of partial dissolution has been noted prior to decrepitation in some inclusions.

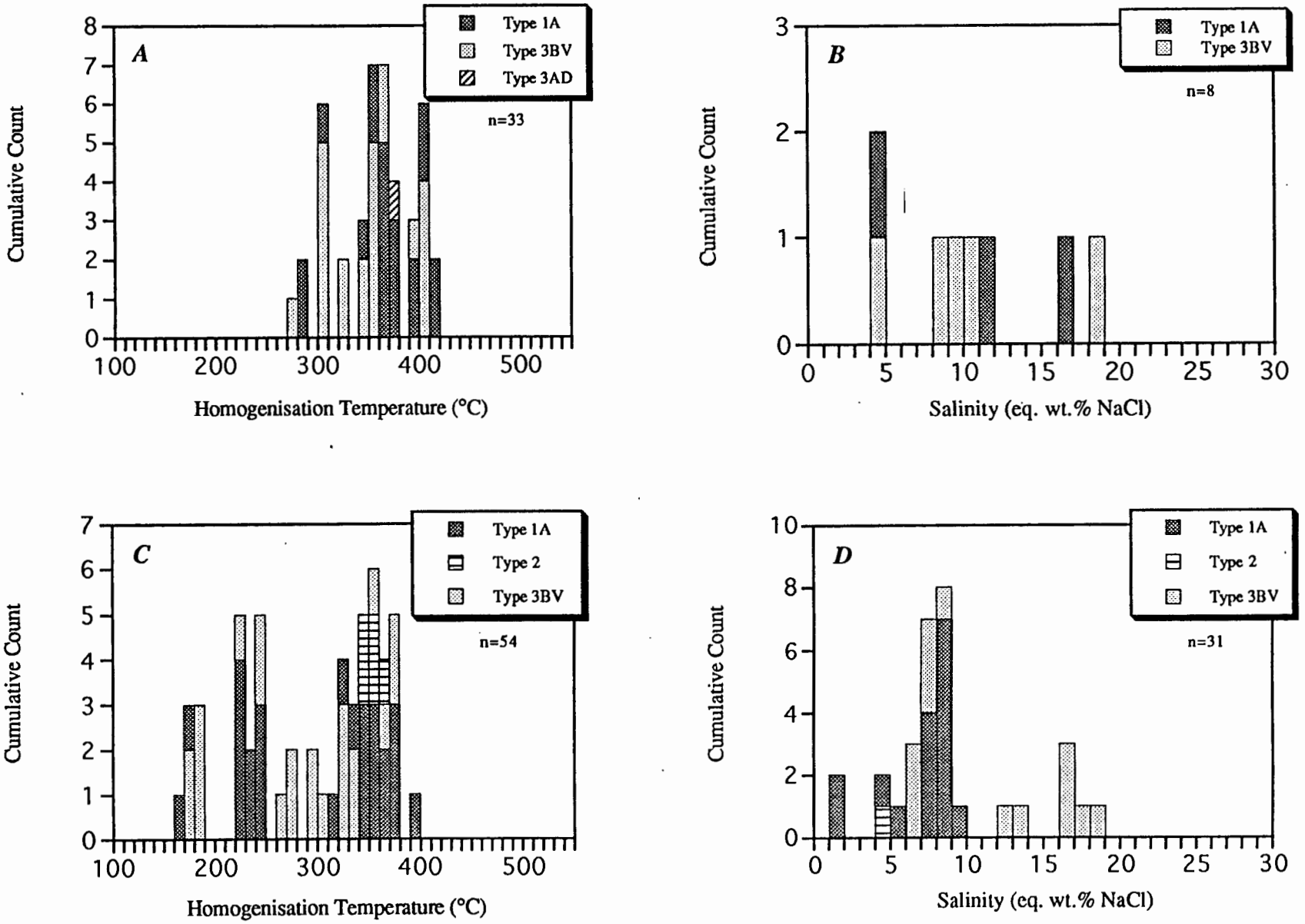


Figure 6.1 Histograms of fluid inclusion data obtained from oxide-silicate stage mineralisation. *A* : Primary homogenisation temperature data. *B* : Primary salinity data. *C* : Secondary homogenisation temperature data. *D* : Secondary salinity data.

Salinity estimates for primary fluid inclusions range between 4 and 19 eq. wt. % NaCl, with a suggested cluster of data between 8 and 12 eq. wt. % NaCl (Fig. 6.1B). Limited freezing data has been obtained due to the poor optical clarity of cassiterite during freezing runs, making meaningful comparisons of the salinities of Type 1A and 3BV fluid inclusions impossible. Secondary fluid inclusions span a similar salinity range (1 to 19 eq. wt. % NaCl), with most between 7 and 10 eq. wt. % NaCl (Fig. 6.1D). Secondary Type 1A fluid inclusions are less saline (≤ 10 eq. wt. % NaCl) than their Type 3BV counterparts (most ≥ 10 eq. wt. % NaCl; Fig. 6.1D).

First melting temperatures for primary oxide-silicate stage fluid inclusions range from -21.2° to -28.0°C, although one specimen yielded a first melting temperature of -54.7°C (Fig. 6.2A). Secondary fluid inclusions from the oxide-silicate stage have first melting temperatures between -21.2° and -28.0°C, with one outlier (-38.9°C; Fig. 6.2B).

6.5.2 Sulphide Stage Fluid Inclusions ...

Type 1A and 3BV are the dominant primary fluid inclusions associated with the sulphide stage of mineralisation, as observed in the earlier oxide-silicate stage (Fig. 6.3). A single primary Type 4 fluid inclusion has been recognised in the sulphide stage veins. Secondary sulphide stage fluid inclusions are predominantly Type 1A with minor Type 1B, 3BV, 3AD, 4 and 5 inclusions also present. The fluid inclusions range from less than 5 μm to 150 μm in diameter, but are typically between 5 μm and 10 μm. Primary fluid inclusions in growth zones are scarce, whereas isolated fluid inclusions occur more frequently.

Homogenisation temperatures for primary sulphide stage fluid inclusions range from 120° to 330°C; most occurring between 170° and 300°C (Fig. 6.3A). These temperatures reflect the mid-range for most sulphide-base metal stages in cassiterite deposits world wide (Kelly & Turneaure, 1970; Taylor, 1979; Haapala & Kinnunen, 1982; Lehmann, 1990; Solomon & Groves, 1994). The data from this study corresponds to the fluid inclusion populations from the sulphide stage noted by Collins (1972), Patterson (1979), Davies (1985) and Holyland (1987) at Renison. Within the primary population Type 1A fluid inclusions form a distinct group between 200° and 250°C, whereas Type 3BV fluid inclusions are distributed bimodally around the Type 1A homogenisation temperatures (150 - 190°C, 250 - 330°C; Fig. 6.3A). Secondary fluid inclusions associated with the sulphide stage are dominated by Type 1A, which range from 100° to 400°C and cluster between 180° and 250°C (Fig. 6.3C). Primary Type 3BV fluid inclusions typically contain a birefringent daughter mineral, whereas secondary Type 3BV fluid inclusions contain multiple (1-5) birefringent daughters. Upon heating, Type 3BV fluid inclusions homogenise to the liquid phase and decrepitate before dissolution of any daughter minerals.

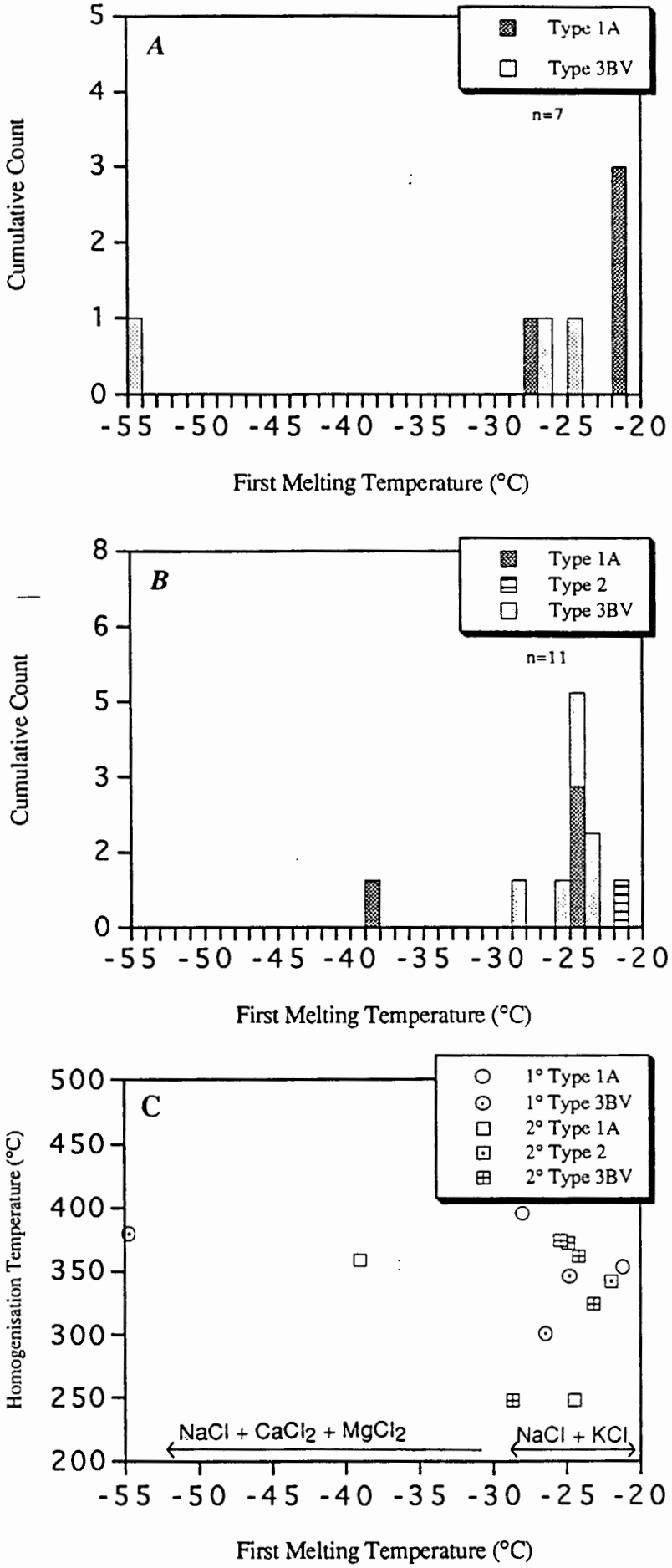


Figure 6.2 First melting temperatures for primary and secondary fluid inclusions from oxide-silicate stage of mineralisation. A : Primary inclusion first melting temperature data. B : Secondary inclusion first melting temperature data. C : First melting temperature v's homogenisation temperature for primary and secondary fluid inclusions types.

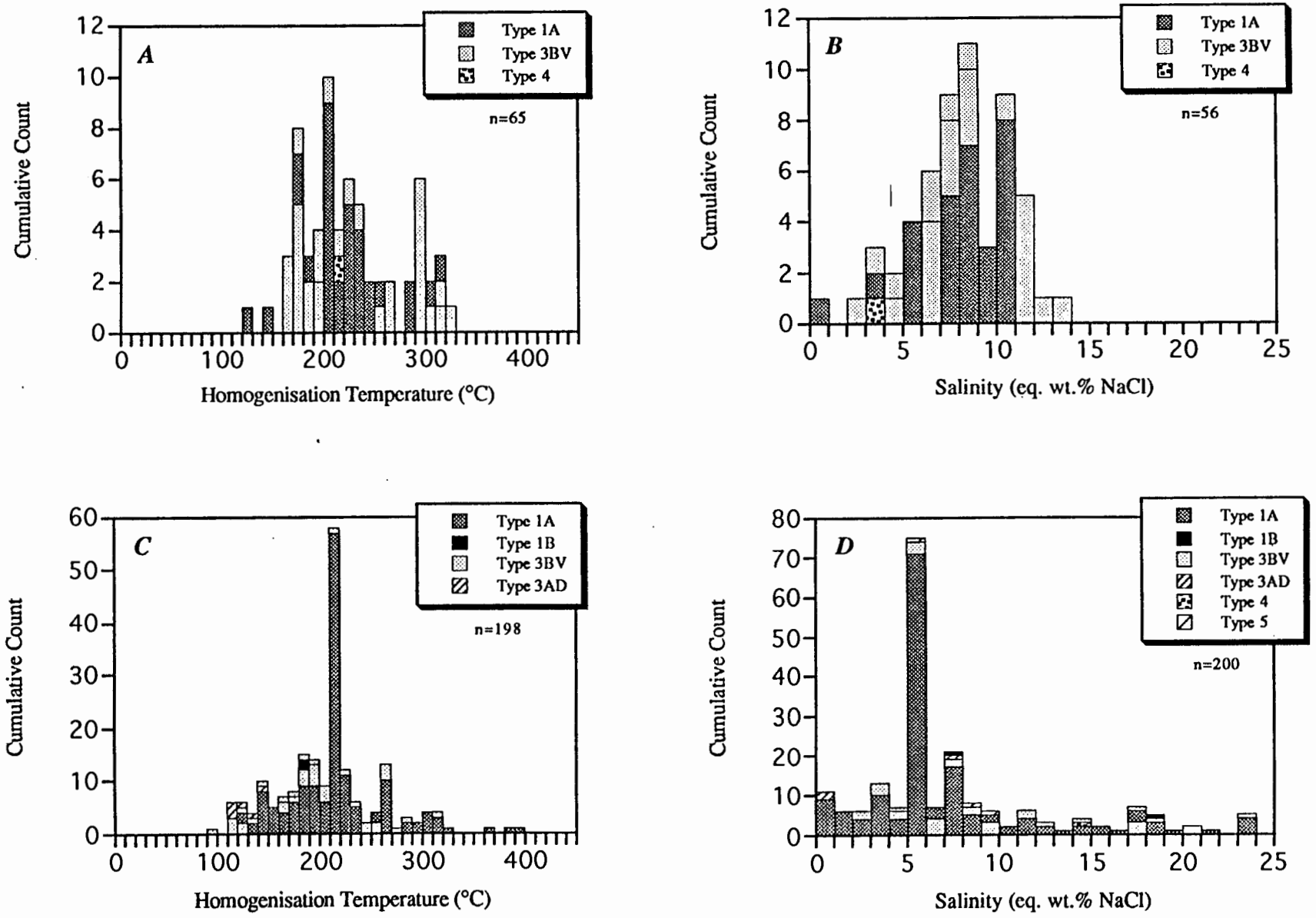


Figure 6.3 Histogram of fluid inclusion data obtained from main sulphide stage mineralisation. *A* : Primary homogenisation temperature data. *B* : Primary salinity data. *C* : Secondary homogenisation temperature data. *D* : Secondary salinity data.

Salinity estimates for primary fluid inclusions associated with the sulphide stage of mineralisation range between 0 and 14 eq. wt. % NaCl, with a maximum between 5 and 12 eq. wt. % NaCl (Fig. 6.3B). Primary Type 1A fluid inclusions cluster between 7 and 11 eq. wt. % NaCl, whereas Type 3BV fluid inclusions span the complete range of salinities. Secondary fluid inclusions yield a much wider range of salinities than their primary equivalents (0 to 24 eq. wt. % NaCl; Fig. 6.3D). Secondary Type 1A fluid inclusions are dominant, covering the entire range of salinities, with a maximum between 0 to 8 eq. wt. % NaCl (Fig. 6.3D).

The first melting temperatures for primary sulphide stage fluid inclusions have mostly been obtained from Type 3BV fluid inclusions and range between -21.0° and -54.2°C. CO_2 triple point behaviour was observed from Type 4 fluid inclusions between -56.7° and -57.8°C (Fig. 6.4A). Data from secondary fluid inclusions have mostly been obtained from Type 1A, which have similar first melting temperatures to the primary fluid inclusions (-20.0° to -55.0°C). However, some secondary fluid inclusions have first melting temperature between -60.3° and -61.8°C (Fig. 6.4B).

6.5.3 Base Metal Stage Fluid Inclusions ...

Primary Type 1A and 3BV fluid inclusions are associated with the base metal stage of mineralisation with Type 1A predominant (Fig. 6.5). Secondary fluid inclusions consist of Type 1A and Type 3BV inclusions with minor Type 5 inclusions. The fluid inclusions range from less than 4 µm to 40 µm in diameter, with most between 5 µm and 10 µm. Primary fluid inclusions in growth zones within quartz crystals are common, as are solitary secondary fluid inclusions.

Homogenisation temperatures for primary base metal stage fluid inclusions are tightly constrained between 150° and 210°C, with minor inclusions occurring at 240° and 280°C (Fig. 6.5A). Primary Type 3BV fluid inclusion homogenisation temperatures cluster between 170° and 210°C, whereas Type 1A fluid inclusions span the complete temperature range for primary fluid inclusions, with a maximum at 160°C (Fig. 6.5A). Secondary fluid inclusions associated with the base metal stage of mineralisation have homogenisation temperatures that range between 90° and 270°C, with a maximum between 120° and 190°C (Fig. 6.5C). Secondary Type 1A fluid inclusions cluster between 150° and 210°C. Secondary Type 3BV fluid inclusions are distributed over the complete temperature range, and constitute the only fluid inclusion type that yield homogenisation temperatures below 150°C. Type 3BV fluid inclusions typically contain a single birefringent daughter mineral, and upon heating, homogenise to the liquid phase and then decrepitate before daughter phase dissolution.

Salinity estimates for primary Type 1A fluid inclusions are bimodally distributed between 0.7 and 3 eq. wt. % NaCl, and 7 to 11 eq. wt. % NaCl (Fig. 6.5B). Type 3BV secondary fluid

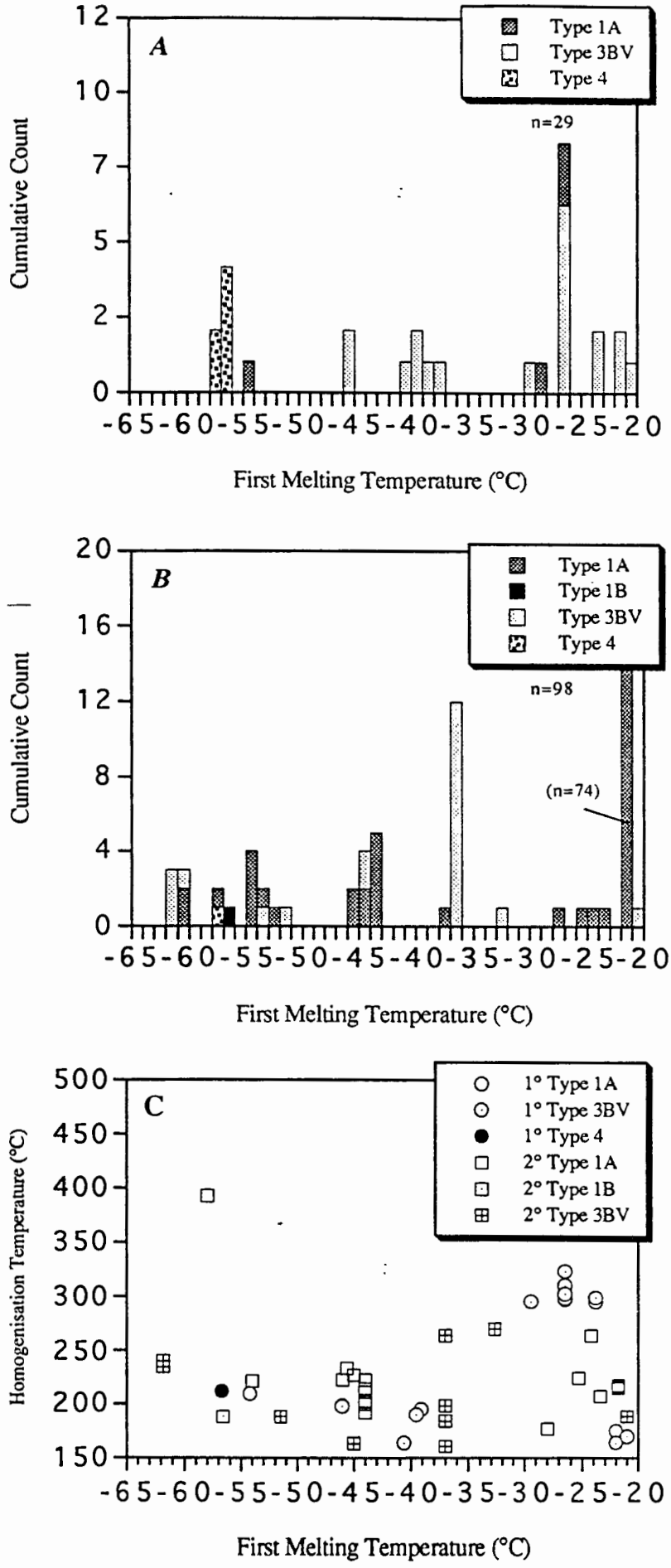


Figure 6.4 First melting temperatures for primary and secondary fluid inclusions from the sulphide stage of mineralisation. *A* : Primary inclusion first melting temperature data. *B* : Secondary inclusion first melting temperature data. *C* : First melting temperature v's homogenisation temperature for primary and secondary fluid inclusion types.

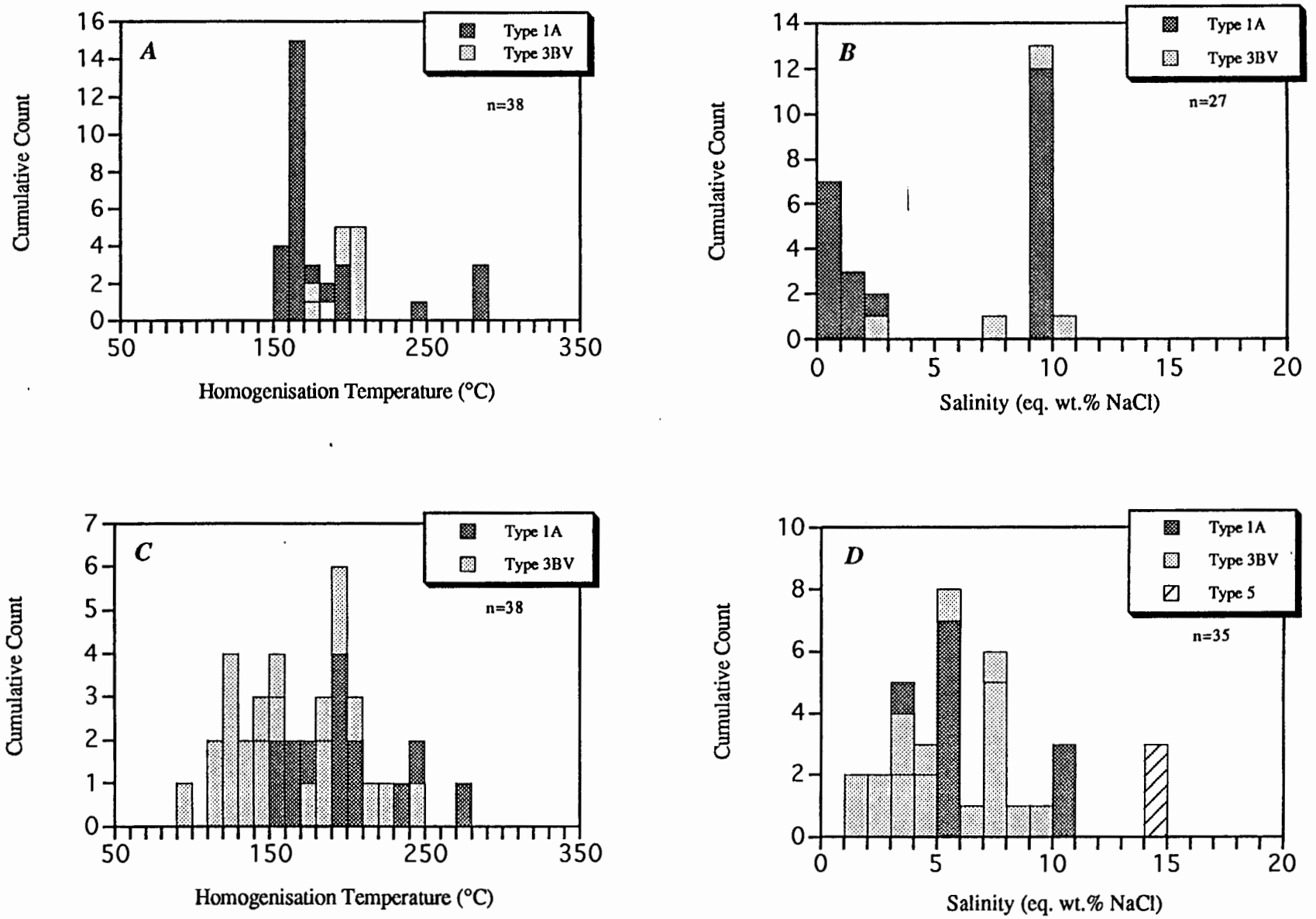


Figure 6.5 Histograms of fluid inclusion data obtained from base-metal stage mineralisation. *A* : Primary homogenisation temperature data. *B* : Primary salinity data. *C* : Secondary homogenisation temperature data. *D* : Secondary salinity data.

inclusions range from 1 to 11 eq. wt. % NaCl, with a maximum between 3 and 8 eq. wt. % NaCl (Fig. 6.5D). Three secondary Type 5 fluid inclusions from specimen 111084 yielded the highest salinity values (14 eq. wt. % NaCl; Fig. 6.5D).

Only one first melting temperature has been obtained from the base metal stage of mineralisation. The secondary Type 1A fluid inclusion yielded a value of -39.7°C (Fig. 6.6A).

6.5.4 Carbonate Stage Fluid Inclusions ...

The carbonate stage of mineralisation contains Type 1A and Type 3BV fluid inclusions (Fig. 6.7) which range in size from less than 4 μm to 30 μm, although most are less than 15 μm. Rare healed fractures in fluorite contain trails of secondary vapour only (Type 5) fluid inclusions, from which no useable microthermometry data was obtained (samples 111180, 111213, and 111231). Primary fluid inclusions associated with growth zones are subordinate to the secondary population of fluid inclusion.

Homogenisation temperatures for primary fluid inclusions range from 143° to 244°C, with Type 1A fluid inclusions mostly yielding temperatures below 190°C, and Type 3BV fluid inclusions temperature above 190°C (Fig. 6.7A). Secondary carbonate fluid inclusions are dominated by Type 1A which have homogenisation temperatures between 101° and 233°C (Fig. 6.7C). Primary and secondary fluid inclusion homogenisation temperatures closely approximate values for the earlier base metal stage of mineralisation. Primary and secondary Type 3BV fluid inclusions associated with the carbonate stage contain a single birefringent daughter mineral, and upon heating homogenise to the liquid phase and then decrepitate before daughter dissolution.

Salinity estimates for primary fluid inclusions have a bimodal distribution, with less saline Type 1A fluid inclusions falling in the range 0.2 to 3.8 eq. wt. % NaCl, and saline Type 3BV fluid inclusions ranging between 7.3 and 10.7 eq. wt. % NaCl (Fig. 6.7B). Secondary Type 1A fluid inclusions cluster between 5.3 and 9.3 eq. wt. % NaCl (Fig. 6.7D). The salinities from the carbonate stage of mineralisation are similar to the salinities recorded from the base metal stage of mineralisation.

The only first melting temperatures obtained for carbonate stage fluid inclusions were from secondary Type 1A fluid inclusions, which ranged from -20.2° to -22.5°C (Fig. 6.6B).

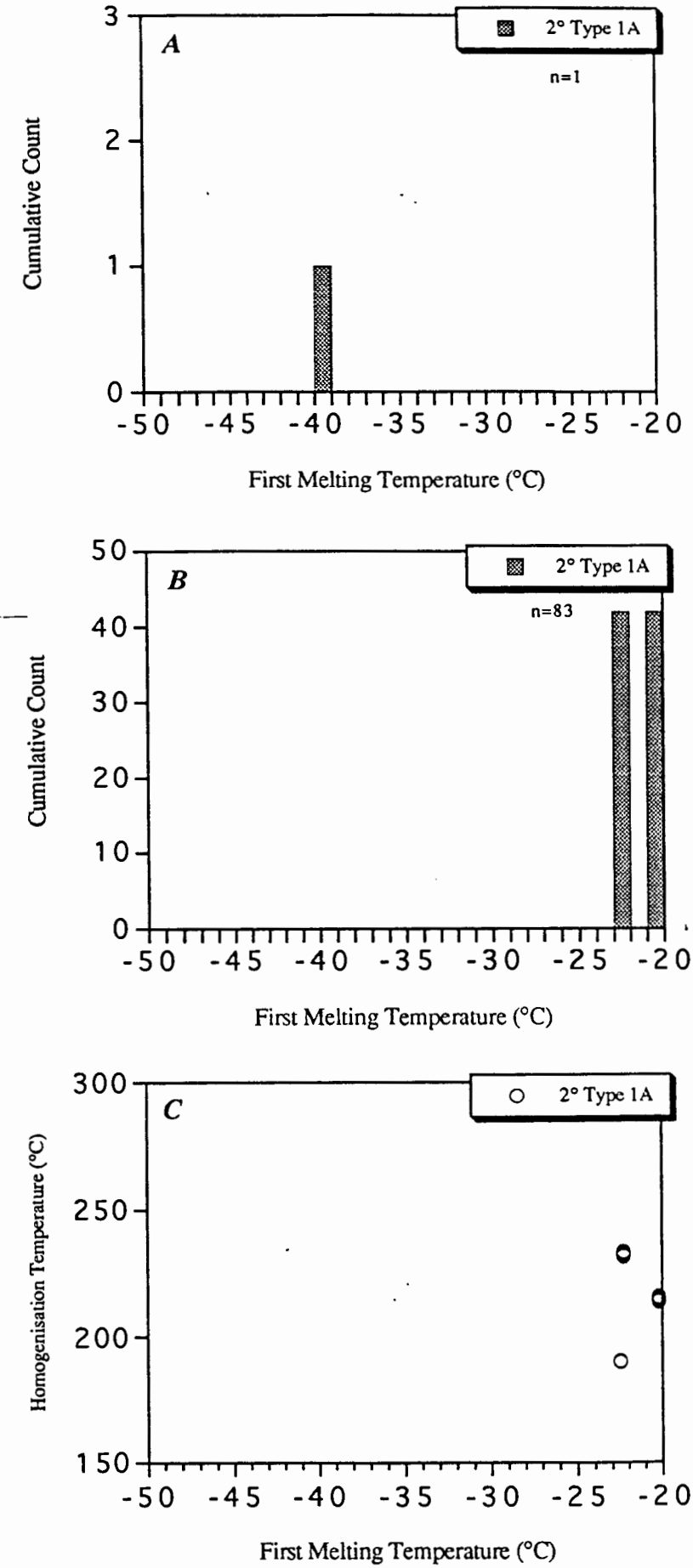


Figure 6.6 First melting temperatures for secondary fluid inclusions from the base metal and carbonate stages of mineralisation. *A* : Secondary inclusion first melting temperatures for base metal stage. *B* : Secondary inclusion first melting temperatures for the carbonate stage. *C* : First melting temperature v's homogenisation temperature for secondary carbonate stage fluid inclusions.

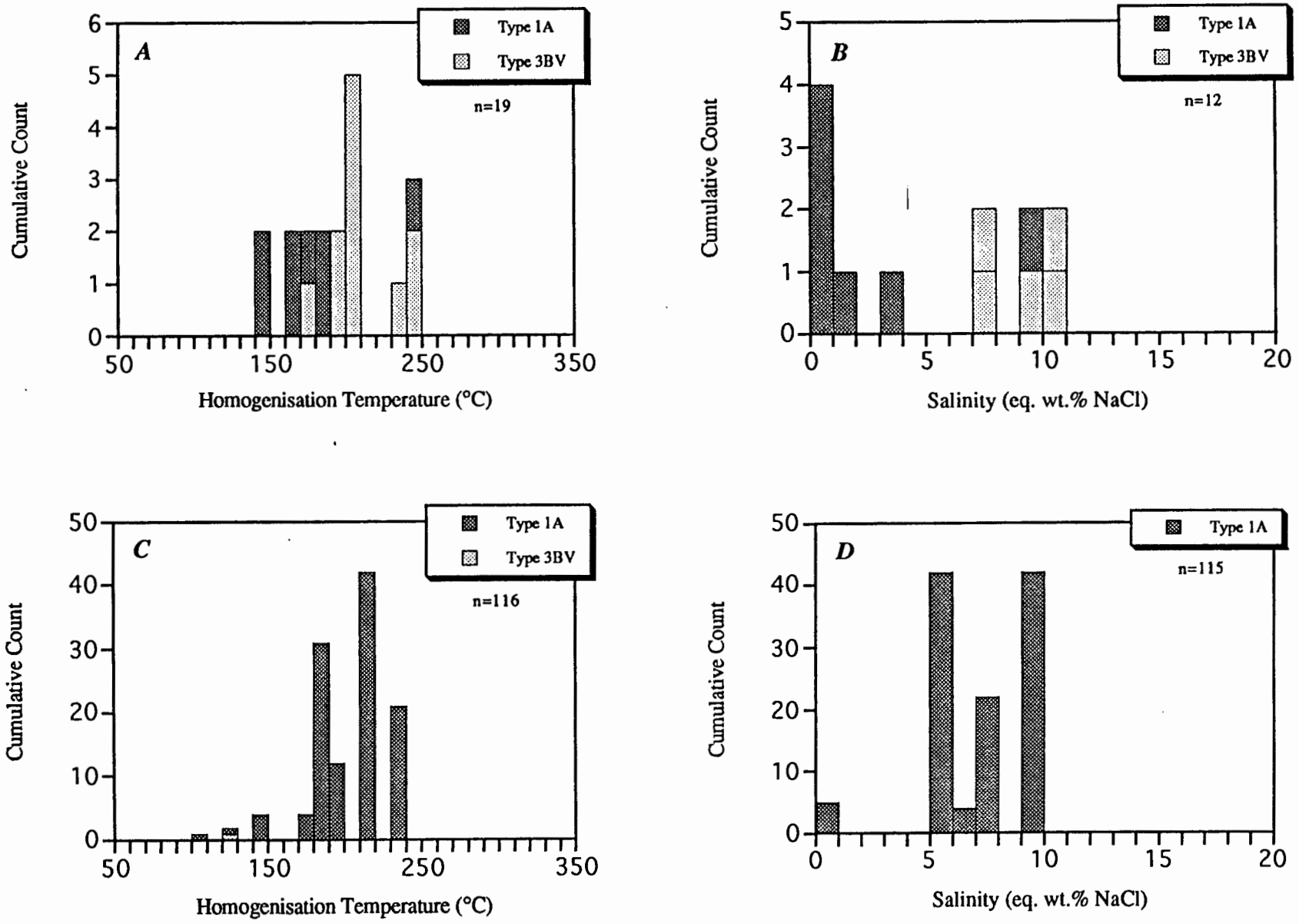


Figure 6.7 Histograms of fluid inclusion data obtained from carbonate stage mineralisation. *A* : Primary homogenisation temperature data. *B* : Primary salinity data. *C* : Secondary homogenisation temperature data. *D* : Secondary salinity data.

6.6 DISCUSSION ...

6.6.1 Spatial Evolution Of The Mineralising Fluids ...

Considerations of the spatial evolution of hydrothermal fluids responsible for each of the four major vein stages from the Federal-Bassett Fault are discussed in the following sections. Longitudinal projections of the Federal-Bassett Fault showing contoured spatial variations in homogenisation data (Figs. 6.8, 6.9 & 6.10) have been constructed based on the following assumptions:

(i) all fluid inclusions from a single stage were trapped at the same time;

(ii) primary fluid inclusion homogenisation temperatures in a sample were representative (average) of the total fluid inclusion population from that particular stage; and/or

(iii) a constant thermal gradient existed throughout the mine region.

It would obviously be difficult to substantiate any of the above assumptions, but based on the consistency of the data collected such assumptions will be considered valid.

6.6.1.1 Oxide-Silicate Stage ...

Homogenisation temperatures for primary fluid inclusions from the oxide-silicate stage of mineralisation show a progressive temperature decrease from >400°C to <300°C from the base of the fault nearest the Pine Hill Granite contact to the top of the mine workings (Fig. 6.8), suggesting that these fluids are sourced from the granite. The almost horizontal nature of the isotherms indicate a near vertical sheet-like flow of the early high temperature fluid through the Federal-Bassett Fault away from an apophysis in the Pine Hill Granite. Structural and mineralogical investigations (Chapters 3 and 5) suggest that the oxide-silicate stage of mineralisation was associated with fault initiation during the forceful emplacement of the Pine Hill Granite. During this stage of mineralisation, some focussing of hotter hydrothermal fluids into the Federal region of the fault (65600N and 66200N) is indicated by the small finger-like projection of the isotherms. Insufficient data is available to draw precise conclusions as to fluid movements in the Rendeep area during the oxide-silicate stage, except to say that high temperature fluids gained access to this area. It is likely that hydrothermal fluids associated with mineralisation in both the Federal and Rendeep regions of the fault originated from the same source.

6.6.1.2 Sulphide Stage ...

Primary fluid inclusion homogenisation temperatures from the sulphide stage of mineralisation define two zones of high temperature fluid focussing above the granite (Fig. 6.9). The two zones correspond to the Federal and Rendeep orebodies. Homogenisation

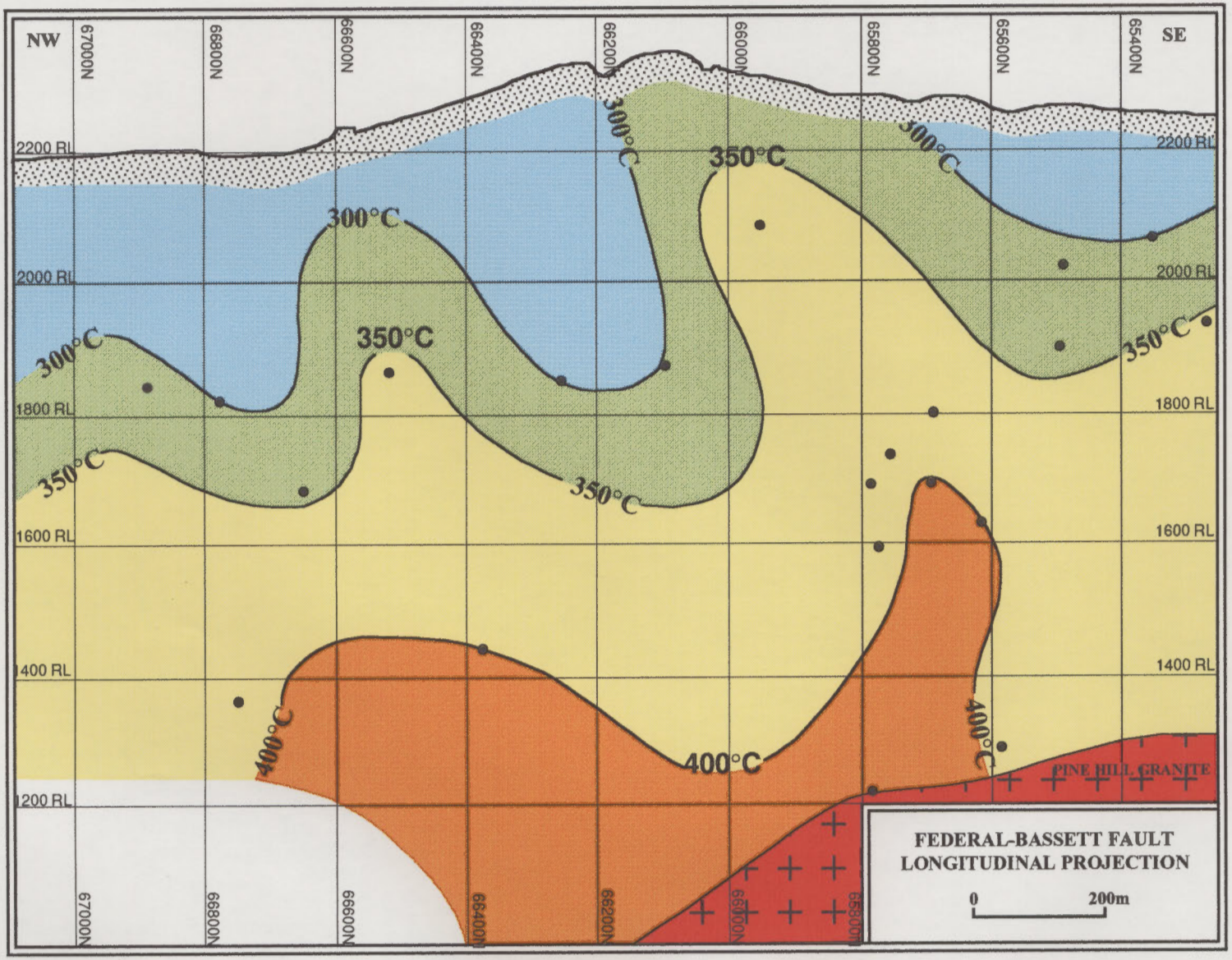


Figure 6.8 **Distribution of homogenisation temperatures for primary fluid inclusions from the oxide-silicate stage of mineralisation plotted on a longitudinal projection of the Federal-Bassett Fault.**

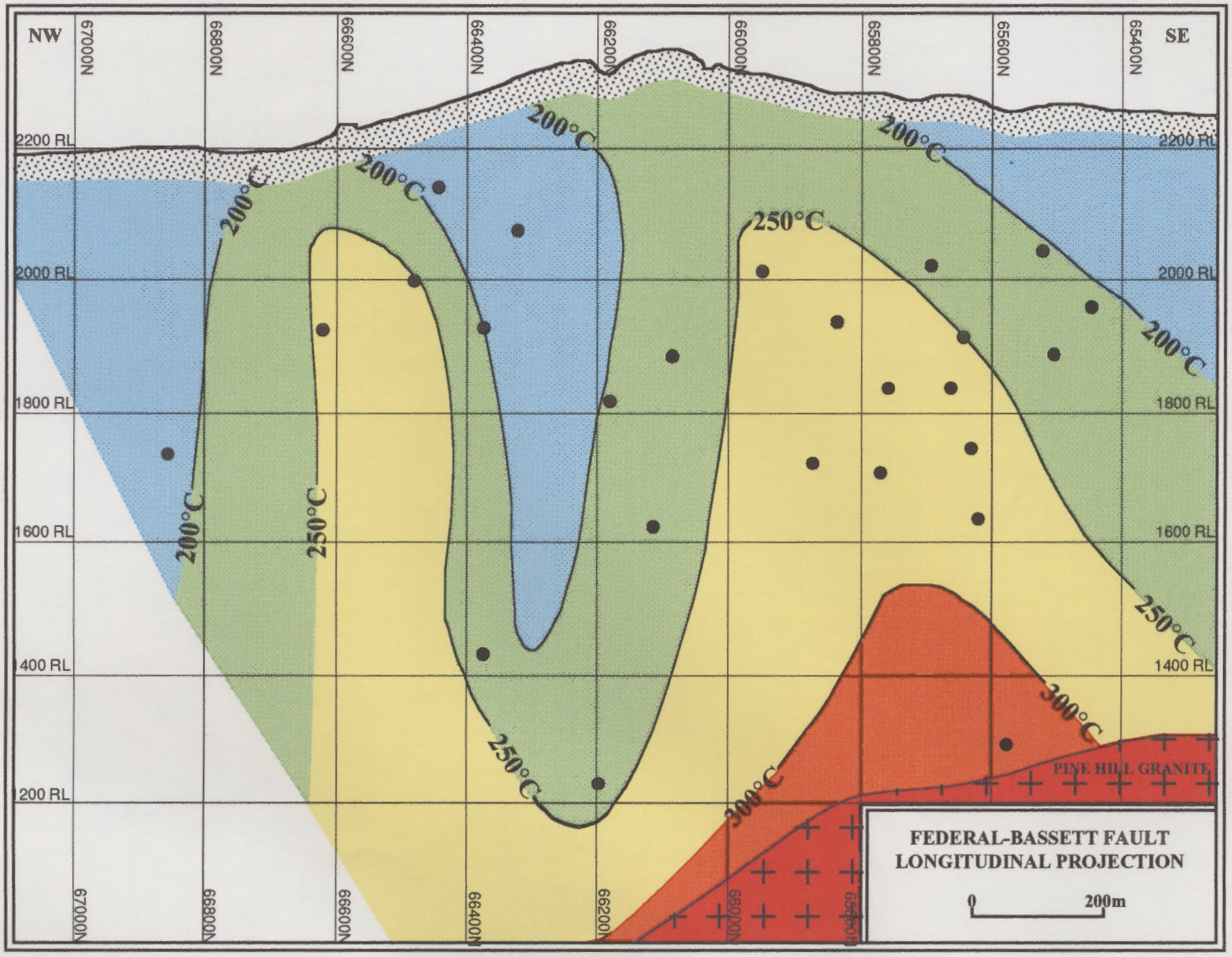


Figure 6.9 **Distribution of homogenisation temperatures for primary fluid inclusions from the sulphide stage of mineralisation plotted on a longitudinal projection of the Federal-Bassett Fault.**

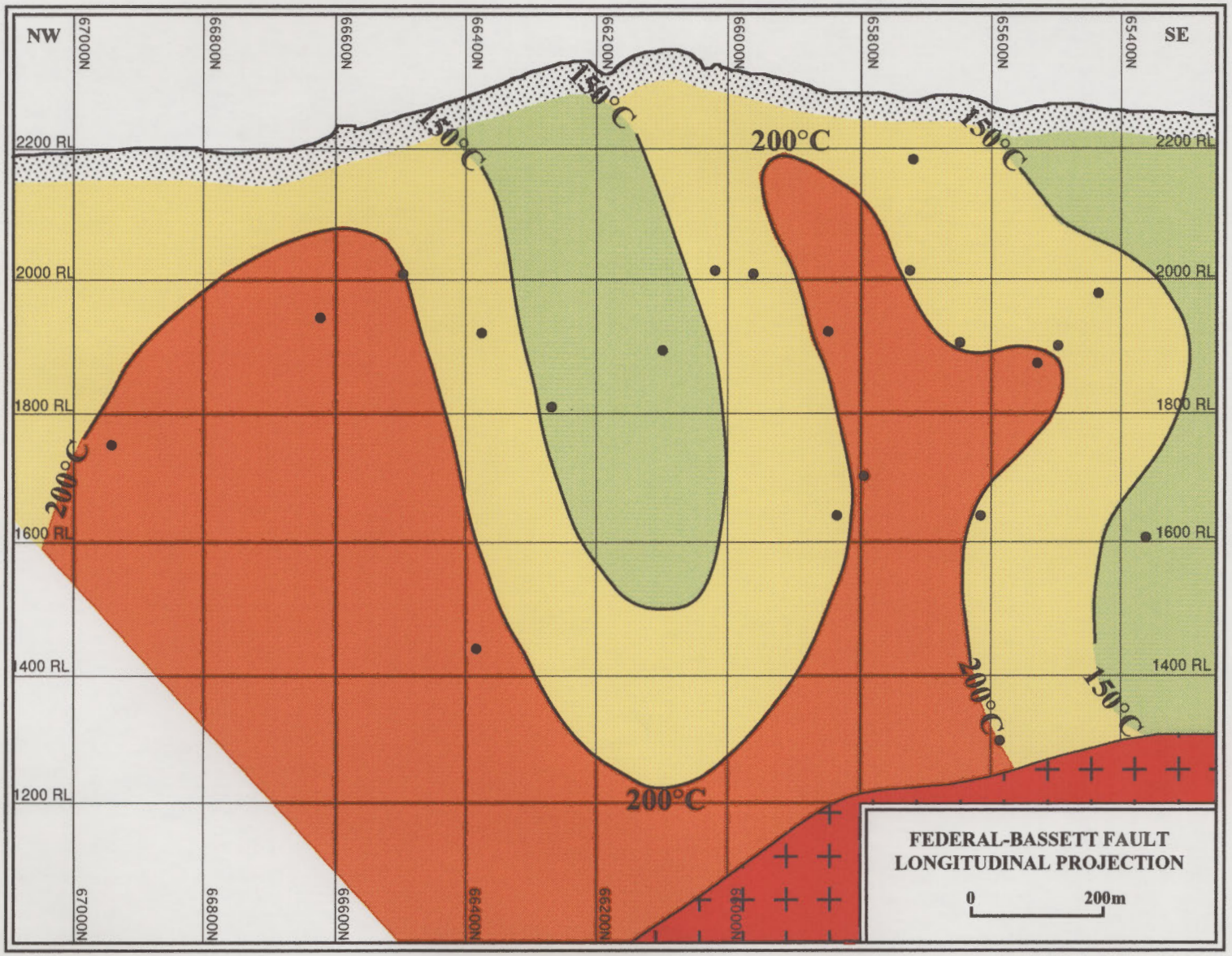


Figure 6.10 **Distribution of homogenisation temperatures for primary and secondary fluid inclusions from both the combined base metal and carbonate stages of mineralisation plotted on a longitudinal projection of the Federal-Bassett Fault.**

temperatures within the higher temperature zones decrease from >300°C directly above the apophysis in the Pine Hill Granite, to ~200°C at the top of the Federal-Bassett Fault. Structural and mineralogical investigations indicate that the high temperature plumes on the Federal-Bassett Fault during the sulphide stage correlate with regions of dilational development associated with dextral wrench reactivation, which initiated the onset of this stage of mineralisation (Chapters 3 and 5).

6.6.1.3 Base Metal And Carbonate Stages ...

Comparison of homogenisation temperatures and salinities from the base metal and carbonate stages of mineralisation on the Federal-Bassett Fault shows a close correlation between the two paragenetic stages (compare Fig. 6.5 and Fig. 6.7). Due to the limited available data, the data sets from both paragenetic stages have been combined on Figure 6.10 to help understand the spatial evolution of homogenisation temperatures and hence interpret possible paths for fluid access during both these stages of mineralisation. Although this figure is more poorly constrained than Figures 6.8 and 6.9, it does highlight the continued influence of the Federal and Rendeep dilational zones on fluid focussing after the sulphide stage of mineralisation. Homogenisation temperatures are typically greater than 200°C in the dilational zones associated with the Federal and Rendeep areas and less than 150°C in the more constricted areas of the fault.

6.6.2 Temporal Variations In Hydrothermal Fluids ...

Evidence for the temporal evolution of the hydrothermal system at Renison can be seen by comparing microthermometric data from the main stages of mineralisation (Figs. 6.11A & B). The system has clearly waned through time with primary fluid inclusion temperatures dropping from 350° - 400°C in the oxide-silicate stage to 150° - 200°C in the late base metal - vug-fill carbonate stages. Figures 6.11A and B indicate that Type 1A and Type 3BV fluid inclusions have been dominant throughout the evolution of the hydrothermal system. The large variation in homogenisation temperatures for primary fluid inclusions from the sulphide stage is probably related to the development of two dilational jogs on the Federal-Bassett Fault which focussed hydrothermal fluids into two high temperature zones of mineralisation. Lower temperatures occurred in the more constricted regions of the fault where more intimate fluid-rock contacts existed. During the final two stages of mineralisation, homogenisation temperatures remained reasonably constant (between 150° and 250°C). Secondary fluid inclusions from each of the paragenetic stages mimic the behaviour of primary populations, but are generally more scattered with respect to temperature (Fig. 6.11b).

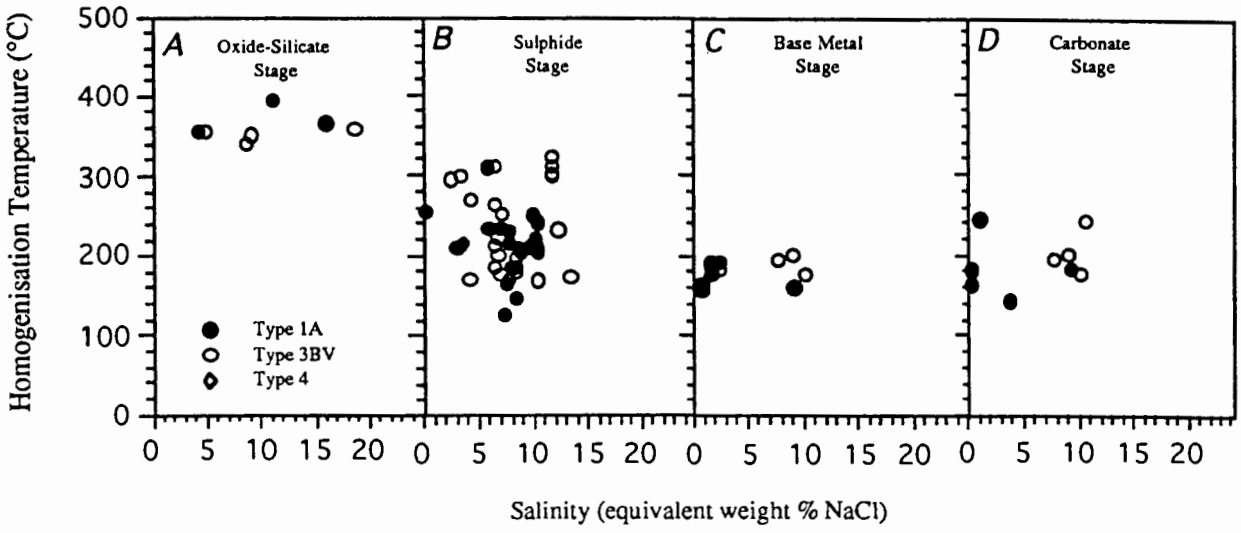


Figure 6.11A Salinity v's homogenisation temperature for primary fluid inclusions from the vein stages of mineralisation. *A* : Oxide-silicate stage. *B* : Sulphide stage. *C* : Base metal stage. *D* : Carbonate stage.

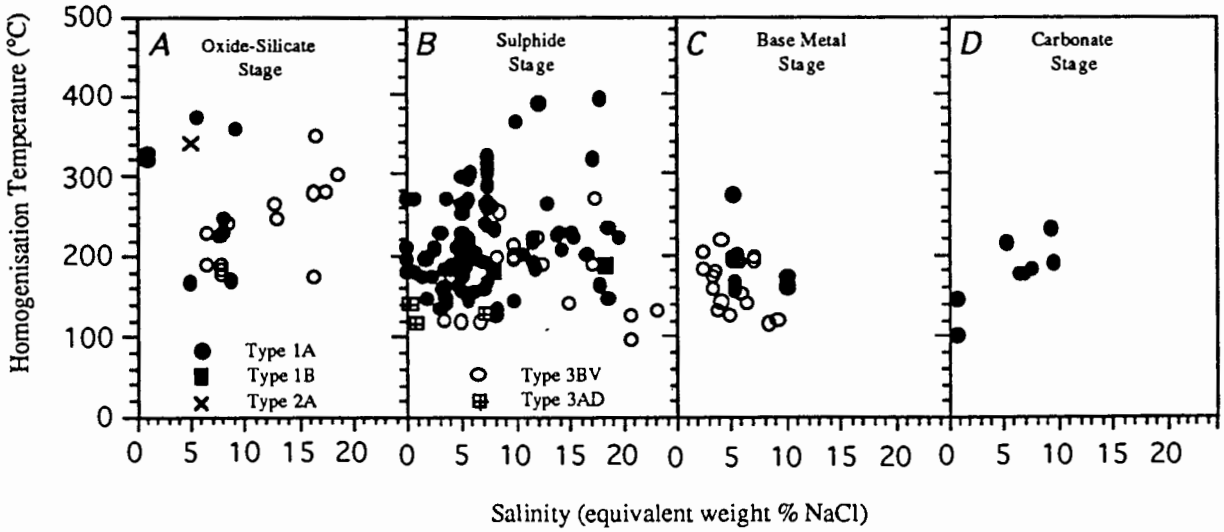


Figure 6.11B Salinity v's homogenisation temperature for secondary fluid inclusions from the vein stages of mineralisation. *A* : Oxide-silicate stage. *B* : Sulphide stage. *C* : Base metal stage. *D* : Carbonate stage.

Salinity variations from the earliest to the latest paragenetic stage are subtle, but are still significant. The salinity of primary fluid inclusions from the oxide-silicate stage range between 4 and 19 eq. wt. % NaCl. Primary fluid inclusions from the sulphide stage are less saline, ranging from 1 to 14 eq. wt. % NaCl. Primary fluid inclusions from the base metal and carbonate stages are less saline than the sulphide stage, with a bimodal distribution between 7 to 11 eq. wt. % NaCl and 0 to 4 eq. wt. % NaCl (Fig. 6.11). It is worth noting that the secondary fluid inclusions associated with both the base metal and carbonate stages are not bimodal in their distribution and occupy the salinity gap observed in the primary fluid inclusion populations for these two stages.

The Renison hydrothermal system evolved from high temperature saline conditions to cooler, more dilute conditions with time; a temporal trend observed in numerous other hydrothermal systems (Grant *et al.*, 1977; Kelly & Rye, 1979; Jackson *et al.*, 1982; Heinrich *et al.*, 1989; Lehmann, 1990). This trend is typically interpreted to be due to progressive incorporation of dilute meteoric fluids into a magmatic dominated regime (Taylor, 1974 & 1979; Patterson *et al.*, 1981; Higgins, 1990).

6.6.3 Chemical Evolution Of The Mineralising Fluid ...

First melting temperatures for the various paragenetic stages have been presented in Figures 6.2, 6.4, and 6.6. The eutectic temperature for a H_2O-NaCl solution is -21.2°C (Borisenko, 1977) and the addition of further salts (e.g., $MgCl_2$, $CaCl_2$, KCl, $FeCl_2$ etc.) will cause the first melting temperature of ice to be depressed (Table 6.3). First melting temperatures for the oxide-silicate stage between -21.2° and -24.5°C are considered to reflect a H_2O-NaCl-KCl dominated salt system. Fluid inclusions with first melting temperatures between -24.5° and -28.0°C may contain additional $MgCl_2$ and/or $FeCl_2$ (Borisenko, 1977; Crawford, 1981). The primary first melting temperature of -54.7°C is close to the eutectic temperature for both the H_2O-NaCl-$CaCl_2$ and H_2O-NaCl-$CaCl_2$-KCl salt systems (Yanatieva, 1946; Borisenko, 1977). The birefringent daughter minerals in Type 3BV fluid inclusions may represent either $CaCl_2$, $MgCl_2$ or $FeCl_2$ crystals. $FeCl_2$, however, does not contribute significantly to the lowering of the eutectic (Chou & Eugster, 1977; Crerar *et al.*, 1978; Bischoff *et al.*, 1981; Weissberg *et al.*, 1979). The first melting temperature of -38.9°C for a secondary Type 1A fluid inclusion may correspond to a H_2O-NaCl-$FeCl_2$ brine, or possibly a H_2O-KCl-$MgCl_2$ rich solution (Borisenko, 1977). Comparison of first melting temperatures and homogenisation temperatures for the oxide-silicate stage of mineralisation (Fig. 6.2C) indicates that the primary and secondary fluid inclusion populations were predominantly high temperature, moderately saline H_2O-NaCl-KCl dominated fluids. This data supports the suggestion of Patterson (1979), Davies (1985), and Holyland (1987) that the primary mineralising fluid was essentially a H_2O-NaCl-KCl rich brine.

Table 6.3: First melting temperatures of eutectics for a number of salt - H_2O systems.

SYSTEM	EUTECTIC (°C)	DENSITY (g/cm^3)	REFERENCE
KCl - H_2O	-10.8	1.1778	Scul' gina, Karchuk and Yanatieva, 1955.
NaCl - H_2O	-21.2	1.199	Comec and Krombach,1932.
KCl - NaCl - H_2O	-23.5	1.234	Borisenko, 1977.
$MgCl_2$ - H_2O	-33.6	–	Borisenko, 1977
$FeCl_2$ - H_2O	-35.0	–	Borisenko, 1977.
$MgCl_2$ - NaCl - H_2O	-35.0	–	Crawford, 1981.
$FeCl_3$ - H_2O	-36.5	–	Borisenko, 1977.
$FeCl_2$ - NaCl - H_2O	-37.0	–	Borisenko, 1977.
$MgCl_2$ - KCl - H_2O	-37.8	–	Borisenko, 1977.
$CaCl_2$ - H_2O	-49.8	–	Yanatieva, 1946.
$CaCl_2$ - KCl - H_2O	-50.5	–	Borisenko, 1977.
$CaCl_2$ - $MgCl_2$ - H_2O	-52.2	–	Borisenko, 1977.
$CaCl_2$ - KCl - NaCl - H_2O	-55.0	1.469	Yanatieva, 1946.
$CaCl_2$ - NaCl - H_2O	-55.0	–	Borisenko, 1977.
$CaCl_2$ - $MgCl_2$ - NaCl - H_2O	-58.0	–	Luzhnaja and Vereshtchetina, 1946.

First melting temperatures for the sulphide stage between -21.2° and -26.5°C are consistent with a H_2O-NaCl-KCl dominated salt system with perhaps trace amounts of additional salts such as $MgCl_2$ and/or $FeCl_2$ (Table 6.3; Borisenko, 1977; Crawford, 1981). The primary and secondary fluid inclusion populations with first melting temperatures between -36.0° to -40.0° are indicative of $MgCl_2$-KCl-$H_2$0 and/or $FeCl_2$-NaCl-H_2O rich systems (Table 6.3). The addition of a further component, $CaCl_2$, into the sulphide stage hydrothermal fluids is reflected by the low first melting temperatures for secondary fluid inclusions of between -51° and -62°C (Table 6.3; Borisenko, 1977; Luzhnaja & Vereshtchetina, 1946; Yanatieva, 1946). A comparison of first melting temperatures versus their respective homogenisation temperatures for the sulphide stage fluid inclusions (Fig. 6.4C) shows that the high temperature fluid inclusions (>300°C), like their oxide stage equivalents, are mostly comprised of H_2O-NaCl-KCl brines. However, with declining temperatures, other components such as $MgCl_2$, $FeCl_2$ and $CaCl_2$ appear to have been added to the

hydrothermal fluids. Limited data available on salts in hydrothermal solutions from other tin deposits suggest that besides NaCl and KCl, other significant components are $MgCl_2$, $FeCl_2$ and $CaCl_2$ (Eadington, 1983; Kwak, 1987; Bottrell & Yardley, 1988; Heinrich *et al.*, 1989). The presence of birefringent daughter minerals in Type 3BV fluid inclusions may suggest that NaCl is in low concentrations or absent due to *salting out effects*, *i.e.*, the reduction in solubility of NaCl and KCl by the addition of Ca or Mg to the hydrothermal fluid (Clynne & Potter, 1977; Potter *et al.*, 1977; Clynne *et al.*, 1981; Crawford, 1981).

The single first melting temperature (-39.7°C) from a late base metal stage secondary fluid inclusion may reflect a $MgCl_2$-KCl-H_20 and/or $FeCl_2$-NaCl-H_2O rich brine (Table 6.3; Borisenko, 1977), but the lack of data prevents any firm conclusions to be made regarding the composition of mineralising fluids during the base metal stage of mineralisation.

The range in first melting temperatures for the carbonate stage fluid inclusions are consistent with a H_2O-NaCl-KCl dominated salt system (Table 6.3; Cornec & Krombach, 1932; Borisenko, 1977). A comparison of first melting temperatures versus homogenisation temperature for the carbonate stage mineralisation (Fig. 6.6C) show that these moderate temperature fluid inclusions (190° to 233°C) are probably a moderately saline H_2O-NaCl-KCl brine.

Figure 6.12 illustrates the number and distribution of carbonate daughter minerals found in Type 3BV primary and secondary fluid inclusions from all paragenetic stages of mineralisation at Renison. Also projected onto the fault plane above 1600 R.L. are the outlines of footwall stratabound carbonate replacement orebodies that contact the fault along their lower most margins. Below 1600 R.L. in the Rendeep area, hangingwall dolomite horizons contact the fault along their upper most margins (see Chapter 5, Fig. 5.9). This figure illustrates that saturation with birefringent (carbonate?) daughter minerals, closely corresponds to the areas where the dolomite horizons contact the Federal-Bassett Fault.

During each paragenetic stage, it appears likely that an earlier higher temperature, moderately saline H_2O-NaCl-KCl rich hydrothermal fluid ascended along the Federal-Bassett Fault before coming in contact and reacting with the dolomite horizons. This interaction changed the chemistry of the brine from H_2O-NaCl-KCl dominated to more complex $CaCl_2$-$MgCl_2$-NaCl-H_2O brines saturated in Ca and Mg carbonate daughter phases. The most significant changes to the hydrothermal fluid compositions obviously took place during main stage stratabound carbonate replacement mineralisation (*i.e.*, sulphide stage; Fig. 6.4) when fluid/rock interaction was greatest.

The chemical evolution of the mineralising fluids described in this study complement the findings of Davies (1985), who demonstrated that during stratabound carbonate

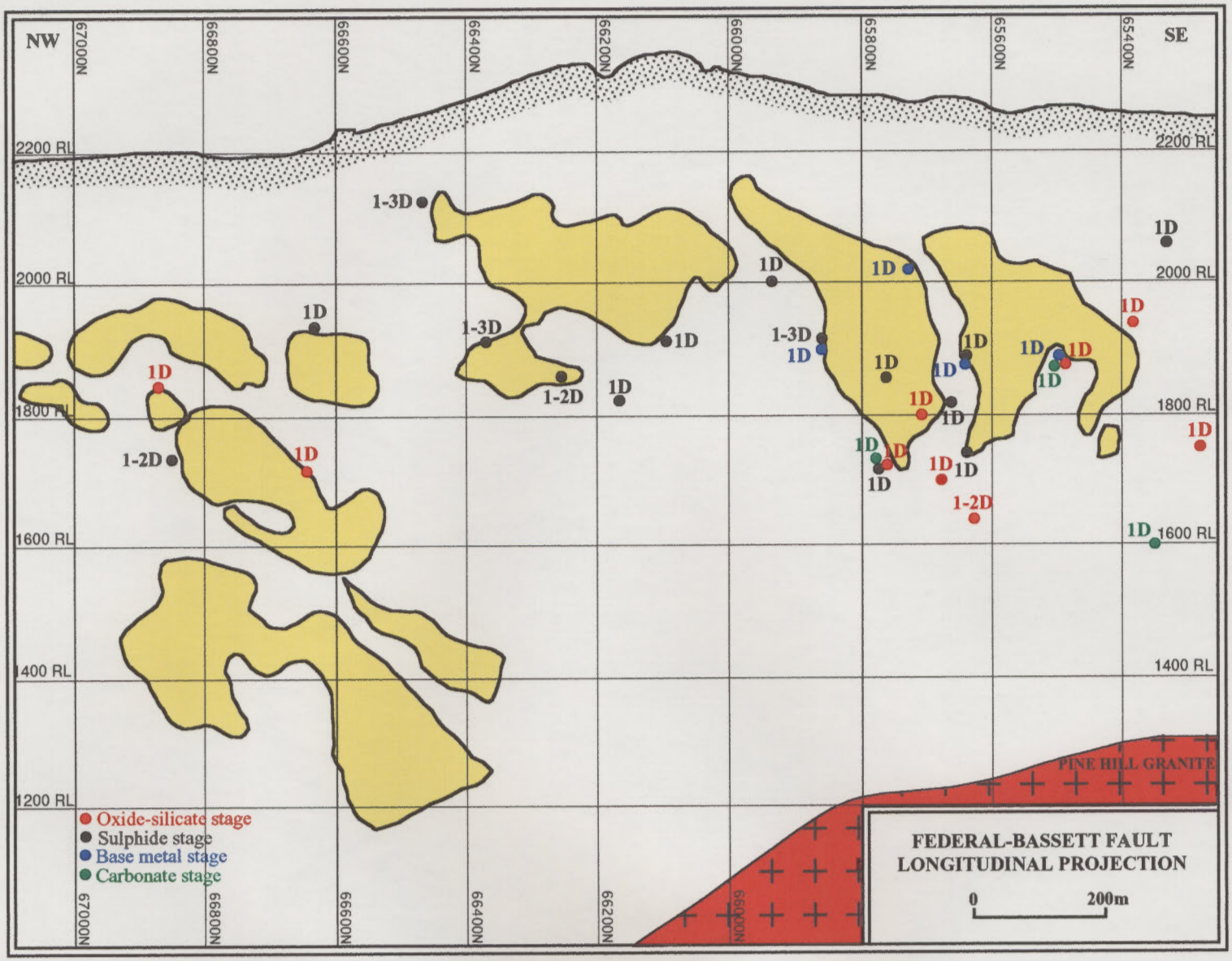


Figure 6.12 Number and distribution of daughter minerals from primary and secondary Type 3BV fluid inclusions from each paragenetic stage, plotted on a longitudinal projection of the Federal-Bassett Fault. Also plotted are the outlines of stratabound carbonate replacement orebodies that contact the fault.

replacement mineralisation, distal to the Federal-Bassett Fault, moderately saline H_2O-NaCl-KCl rich fluids reacted with the dolomite horizons and became increasingly enriched in Ca and Mg.

6.6.4 Pressure - Depth Estimates ...

Pressure - depth estimates have been performed previously at Renison. Groves (1968) proposed maximum depths of 7468 m based on estimates of overburden thickness, which correspond to pressures of approximately 2 kbars lithostatic or 750 bars hydrostatic. Patterson (1979) and Patterson *et al.* (1981) estimated fluid pressures during mineralisation were in the order of 1 - 2 kbars based on thermal metamorphic mineral assemblages. Davies (1985) considered the average fluid pressures from CO_2-bearing fluid inclusions in the hydrothermal carbonate zone of the Penzance orebody at Renison to be ~400 bars, and Holyland (1987) obtained a range of pressures from 300 - 850 bars (mean 500 bars) on CO_2-bearing fluid inclusions. Pressure calculations by Davies (1985) and Holyland (1987) relied on visual estimation of molar volumes of the three phases present in CO_2-bearing fluid inclusions, and therefore some variations in these estimates are expected.

A quartz crystal from oxide-silicate stage pyrrhotite - arsenopyrite - quartz - pyrite mineralisation on the Federal-Bassett Fault (sample 111107 at 65960N and 2100 R.L.) contained a set of five isolated (secondary) fluid inclusions which exhibited critical homogenisation phenomenon. This set of Type 2 fluid inclusions homogenised over the temperature range 342° to 363°C by gradual meniscus fading without a change in the size of the vapour bubble. First melting (eutectic temperature) and final melting (ice) temperatures of -22.0° and -3.0°C respectively, were obtained from one fluid inclusion, indicating that the fluids were H_2O-NaCl-(KCl)-rich, with a salinity of 4.9 eq. wt. % NaCl. Estimates for the hydrostatic pressure associated with these fluid inclusions range between 132 and 336 bars (Brown & Lamb, 1989; Brown, 1989) which corresponds to a depth of emplacement between 1345 m and 3425 m (hydrostatic), or 498 m to 1268 m (lithostatic). Similar hydrostatic pressure estimates (240 to 280 bars) were made by Hajitaheri (1985) based on critical phenomena in fluid inclusions from mineralisation associated with the Heemskirk Granite.

Fluid pressures in most natural hydrothermal systems are typically somewhere between hydrostatic and lithostatic conditions (Roedder & Bodnar, 1980; Roedder, 1984). At Renison, a hydrostatic regime is considered to have been operative in both the oxide-silicate and sulphide stages of mineralisation. Evidence for this interpretation comes from the earlier structural and mineralogical investigations, which indicate:

(i) Fault initiation in the mine area was associated with 700 m of dip-slip movement and coeval with the oxide-silicate stage of mineralisation.

(ii) Dextral wrench reactivation, coeval with the main sulphide stage of mineralisation, created two major dilational zones along the Federal-Bassett Fault associated with the Federal and Rendeep orebodies.

The Devonian Pine Hill Granite occurs beneath the Federal area of the mine at 1200 R.L. Based on the calculated depth to mineralisation it is inferred that the depth of emplacement of the Devonian Pine Hill Granite, responsible for fault initiation and coeval with the oxide-silicate stage of mineralisation, was between 2245 m and 4325 m beneath the palaeo-surface during the Devonian. These estimates agree with Varlamoff (1978), who would classify Renison-style deposits as upper-mesoabyssal and forming close to a granitic intrusion at 2 to 4 kilometres depth, at pressures between 200 - 400 bars (hydrostatic) and 500 - 1000 bars (lithostatic).

6.6.4.1 Pressure Corrections ...

Pressure corrections for homogenisation temperatures from fluid inclusions not undergoing critical homogenisation behaviour, using the curves of Potter (1977), result in a correction of less than 15°C for a 10 eq. wt. % NaCl fluid inclusion at 300°C. As a consequence, pressure corrections to homogenisation temperatures for the Renison data set have not been performed. Obviously pressure corrections based on measurements in the $NaCl-H_2O$ system are not applicable to the more complex $CaCl_2-MgCl_2-NaCl-H_2O$ rich hydrothermal fluids. However, the thermodynamic behaviour of $CaCl_2$-fluids show only marginal variance relative to NaCl brines (Potter & Clynne, 1978) and therefore errors in pressure correction estimates would probably be minimal.

6.6.5 Evidence For Phase Separation ...

Fluid inclusion evidence for phase separation (coexisting liquid-rich and vapour-rich inclusions; Shepherd *et al,* 1985) is absent from the oxide-silicate and sulphide stages at Renison. Pressure/depth estimates and homogenisation temperatures indicate that these stages formed at depths greater than the two-phase field predicted by the boiling curves of Haas (1971) explaining the absence of textural, mineralogical and fluid inclusion evidence for boiling from cassiterite-bearing stages of the paragenesis. Boiling is therefore concluded not to have been important for cassiterite deposition.

Possible evidence for CO_2 effervescence occurs in one quartz sample from the sulphide stage of mineralisation (sample 111140). A set of five isolated Type 4 CO_2-rich fluid inclusions with variable liquid/vapour ratios homogenised to the liquid phase between 205° to 228°C. No results were obtained in the gas-rich population.

Good secondary fluid inclusion evidence for phase separation occurs in late fractures, hosted by either fluorite or quartz, which cross-cut the sulphide, base metal and carbonate stages of mineralisation (e.g., samples 111293, 111159, 111231). Some of these late fractures host secondary trails of liquid only, liquid - vapour and vapour only fluid inclusions, which indicate that phase separation took place in the Federal-Bassett Fault somewhere beneath the sample locality at some indeterminate time after the main stages of mineral deposition. The sparse evidence for phase separation together with the mesothermal pressure/depth estimates for mineralisation during cassiterite deposition, and the lack of textural and mineralogical evidence for boiling, strongly suggest that these fractures post date cassiterite deposition. Holyland (1987) recognised the presence of vapour-only fluid inclusions in the dilated parts of the Federal-Bassett Fault and considered they were coeval with brecciation associated with the carbonate stage of mineralisation (Chapter 5; Plate 5.5c) resulting from a,"..... *lowering of the differential stress magnitude under the influence of pressurised fluid at the base of the fault which preceded the arrival of fluids from below. This movement, and consequent rapid pressure drop, formed implosion breccias in the Federal segment of the fault. The pressure drop could, in addition, promote flashing of the local pore fluids to steam, promoting the dry fluid inclusions.*"

6.6.6 CO_2 Concentrations ...

Dissolved carbon dioxide in hydrothermal solutions has significant effects on the physical and chemical controls of ore deposition in base metal deposits. Significantly, estimates of salinity (total dissolved salts) based on fluid inclusion ice melting measurements are frequently in error in the absence of an independent determination of the CO_2 content of the fluid inclusions due to the contributions of dissolved CO_2 on the freezing point depression (Hedenquist & Henley, 1985).

In this study, rare Type 4 CO_2-rich fluid inclusions have only been detected on the Federal-Bassett Fault from the sulphide stage of mineralisation (samples 111140 & 111143); coincident with the formation of massive stratabound carbonate replacement mineralisation. Bulk extraction analysis of fluid inclusions from all paragenetic stages at Renison by Patterson (1979) indicate that between 0.002 and 0.022 molal CO_2 is present. If CO_2 is in significant quantities (greater than ~ 0.1 molal), it will affect salinity and fluid pressure estimates. Because CO_2 concentrations in the fluid inclusions from the Federal-Bassett Fault at Renison are thought to be less than 0.1 molal, its effect is considered to be minimal.

6.7 SUMMARY AND CONCLUSIONS ...

At Renison, five paragenetic vein stages are associated with the Federal-Bassett Fault. Four of these stages contain workable fluid inclusions. Microthermometric analyses have found

that each mineralogical stage has its own distinctive spatial, temporal and geochemical signature that can be used to reconstruct the history of hydrothermal fluid evolution along the fault.

The earliest episode of mineralisation recognised at Renison is the oxide-silicate stage. Fluid inclusion studies indicate that high temperature (>400°C), moderately saline (~12 eq. wt. % NaCl), H_2O-NaCl-KCl rich hydrothermal fluids ascended the Federal-Bassett Fault above an alteration zone associated with an apophysis in the Devonian Pine Hill Granite. Fault initiation and cassiterite mineralisation are considered to have been coeval with granite emplacement, at a depth of 2245 m to 4325 m beneath the Devonian palaeo-surface. The system operated at, or near, hydrostatic pressures of 132 to 336 bars. The CO_2-deficient hydrothermal fluids did not undergo phase separation. Homogenisation temperatures for the oxide-silicate stage, in association with structural and mineralogical observations, indicate that the migration of hydrothermal fluids occurred by sheet-flow, synchronously to or shortly after fault initiation. The close genetic link between tin (± tungsten) deposits and granitic intrusions world-wide has long been recognised (Landis & Rye, 1974; Kelly & Rye, 1979; Taylor, 1979; Collins, 1981; Haapala & Kinnunen, 1982; Jackson *et al.*, 1982; Eadington, 1983; Andrew & Heinrich, 1984; Heinrich, 1986 & 1990; Higgins, 1990; Kigai, 1986; Ren & Walshe, 1986; Kwak, 1987; Sun & Eadington, 1987; Bottrell & Yardley, 1988; Lehmann, 1990; Rankin *et al.*, 1992; Pollard *et al.*, 1991; Heinrich & Ryan, 1992; Ahmad, 1993; Solomon & Groves, 1994). Based on the data presented in this study, the fluids associated with mineralisation at Renison are interpreted on fluid inclusion evidence to be magmatic in nature, and sourced from the apophysis in the underlying Devonian Pine Hill Granite at the base of the Federal-Bassett Fault. This interpretation concurs with previous investigators at Renison, who have also proposed a magmatic source for the hydrothermal fluids responsible for cassiterite deposition (Collins, 1972; Patterson, 1979; Patterson *et al.*, 1981; Davies, 1985; Holyland, 1987; Barber, 1990).

Brittle reactivation of the Federal-Bassett Fault by a dextral wrench caused two major dilational jogs to develop along the fault in the Federal and Rendeep areas. Fault reactivation allowed ingress of a second generation of hydrothermal fluids that formed the sulphide stage of mineralisation. Hydrothermal fluids associated with this stage were focussed into the two dilational zones and resulted in two high temperature plumes (>300°C) accompanied by cassiterite deposition. Stratabound carbonate replacement mineralisation occurred during interaction of the brine with the dolomite horizons, causing modifications of the chemistry of the ascending, moderately saline (~ 8 eq. wt. % NaCl) hydrothermal fluid from a H_2O-NaCl-KCl rich brine to a more complex $CaCl_2$-$MgCl_2$-NaCl-H_2O brine. Fluid inclusion evidence shows that the mineralising fluids became saturated with carbonate daughter minerals where the dolomite horizons contact the Federal-Bassett Fault.

The hydrothermal fluids responsible for the base metal and carbonate stages of mineralisation have similar fluid inclusion characteristics. The H_2O-NaCl-(KCl) rich hydrothermal fluids have bimodal salinities (~1 and ~9 eq. wt. % NaCl), and were focussed into pre-existing dilational zones at or near 200°C. The bimodal nature of the salinities may reflect entrainment of meteoric fluids during the waning stages of mineralisation. Meteoric water is a typical component of late stage hydrothermal fluids in tin ore systems (Kelly & Rye, 1979; Grant *et al.*, 1980; Jackson *et al.*, 1982; Andrew & Heinrich, 1984; Sun & Eadington, 1987). At Renison, Patterson (1979) has suggested, based on hydrogen/deuterium and oxygen isotopes, that the early exsolved magmatic aqueous phase was replaced by a probable heated contemporary ground water in the late stages of mineralisation. Fluid inclusion evidence from this investigation shows that the higher temperature primary fluid inclusions from both the base metal and the carbonate stages occur in dilational zones, are more saline, and more likely to be saturated with carbonate daughter minerals. These fluid inclusions may represent the last gasps of the magmatic hydrothermal system as it mixed with heated, low salinity meteoric fluids. Stable isotope investigations have been undertaken to assist in the interpretation of the source(s) for the mineralising fluids at Renison.